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TRACK WIDTH MEASUREMENTS IN NUCLEAR EMULSIONS

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av

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GENERAL BACKGROUND

"Actually, the word cosmic rays, at the time the name was given, was a curious double confession of ignorance - cosmic meaning that we did not know from where they were coming and rays meaning that we did not know what they were."

(van de Hulst, at a colloquium in Bombay, 1968).

To follow the development of a consistent theory about the origin and the accelerating mechanism of cosmic radiation, we have to learn from the observed details in the charge spectrum of the arriving particles. It is but recently that the experimental techniques have allowed sufficient charge resolution to uniquely identify the cosmic rays up to iron with charge number $Z=26$. Shapiro and Silberberg (1) have provided an excellent, comprehensive review of the work up to 1970 on cosmic rays with $Z \geq 3$, characterized as heavy primary nuclei.

When using high-altitude balloons to investigate

the charge composition of primary cosmic ray nuclei, one has to allow for the production of secondaries resulting from breakup of the primaries in collision with atomic nuclei in the overlying atmosphere. The required extrapolation of observed abundances to the top of the atmosphere involves statistical uncertainties as well as uncertainties due to insufficient knowledge of fragmentation cross-sections in nucleus-nucleus collisions. In the last few years investigations of the composition and energy spectrum of the primary radiation have been performed outside the atmosphere and, in some cases, also outside the magnetosphere with instruments carried by satellites and space-probes. Several experiments have been reported in which nuclear emulsions were used as particle detectors (2-4). When using an emulsion which registers all ionizing particles, the necessity of keeping a low background level in the detector severely limits the time during which the emulsions can be exposed to the cosmic radiation. The background problem arising in space experiments of long duration can however be overcome by using less sensitive nuclear emulsions, which do not register lightly ionizing particles.

The use of less sensitive nuclear emulsions in studies of the heavier part of the cosmic ray charge spectrum has so far been limited by the technique of measurements. In the Gemini XI experiment (3) a satisfactory resolution was reached between consecutive

charges up to $Z \approx 10$ by means of δ -rays and grain density measurements in emulsions of various sensitivities. Ivanova et al. (4) have studied the abundance of very heavy cosmic particles by using less sensitive emulsions exposed in the space-probes Zond 5 and Zond 7. The charge estimation is based on the method of track photometry and the result is as yet merely preliminary.

SUMMARY OF THESIS

This thesis concerns the problem of the identification of heavy primary cosmic ray particles. Nuclear research emulsions of two types have been used as particle detectors: Ilford G5, which registers all ionizing particles, and the less sensitive Ilford K2, in which slow electrons produce tracks of only a few grains. Above all, the usefulness of the less sensitive emulsion has been investigated. The charge determination of the registered particles is based on photometric mean track width measurements carried out in accordance with methods developed by the Cosmic Ray Division at the University of Lund (5, 6).

In this thesis the following three publications have been included:

- I. The use of Ilford K2 nuclear emulsions in studies of the cosmic ray charge spectrum.

Nucl Instr and Meth 100, 149 (1972)

- II. The relation between restricted energy loss and track width in nuclear emulsions.

Nucl Instr and Meth (1972)

(in collaboration with M Jensen and L Larsson)

- III. On the width of heavy ion tracks in nuclear emulsions - A study of the energy dose concept for ion velocities $\beta \leq 0.3$.

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(in collaboration with L. Jacobsson)

Reports were given at:

- 1) The Conference of the Swedish National Committee for Physics,
Lund, Sweden 1972.

- 2) The VIIIth International Conference on Nuclear Photography and Solid State Track Detectors.
Bucharest, Romania 1972.

In paper I the possibility of using less sensitive nuclear emulsions as particle detectors, in investigations of the cosmic ray charge spectrum, has been studied. Photometric mean track width measurements have been carried out on tracks from about 200 primary cosmic ray particles with the nuclear charge Z in the interval $5 \leq Z \leq 26$. The particles stopped in a nuclear emulsion stack of type Ilford K2, exposed to the primary cosmic radiation in a balloon flight from northern Canada in 1967. The measurements are corrected for different emulsion and measuring effects, and a charge distribution is given. The standard deviation of the experimentally determined charge values is about 0.3 units of charge in the whole spectrum, when the residual range interval of 0.5 to 10.5 mm has been used for identification. The resolution compares well with the charge resolution obtained with other types of cosmic ray detectors.

Papers II and III deal with the problems of the formation of heavy ion tracks and of the calibration of mean track width measurements in nuclear emulsions. A number of attempts have been made to relate the grain density of tracks in nuclear emulsions with parameters of ionization (7). In paper II a parameter of energy loss is discussed, which only considers energy transfers to secondary electrons up to a fixed maximum value. This parameter, which is called restricted energy loss (REL), differs from the Bethe-Bloch formula for the ave-

range energy loss by the exclusion of a certain fraction of long delta rays. In track width measurements these long delta rays do not contribute to the measured quantity. Photometric mean track width (MTW) measurements of tracks of heavy cosmic ray particles with $4 \leq Z \leq 26$ have been performed in two types of emulsion, Ilford G5 and Ilford K2. Relations between MTW and REL are presented. From these data it is concluded that in a limited velocity interval the REL parameter is a convenient means of describing the track width of heavy ions. Thus, this parameter can be used for the calibration of photometric track width measurements in nuclear emulsions.

Paper III reports a detailed experimental study of the width of heavy ion tracks in emulsion, which has been performed using a photometer that measures light absorption profiles of the tracks. The tracks are produced by primary cosmic ray particles with $6 \leq Z \leq 26$, and with the ion velocity lower than $0.3c$. Two types of emulsion with different sensitivities, Ilford G5 and Ilford K2, have been investigated. The experimental track widths are compared with calculations of the spatial distribution of energy dose delivered by a heavy ion passing through a medium. These calculations have been made following the formalism of the track formation theory developed by Katz and coworkers (8, 9). Fairly good agreement between experiment and theory is established for the

measurements in Ilford K2 emulsion. For the measurements in the sensitive Ilford G5 there is some disagreement between experimental and theoretical track widths.

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